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Stabilizing the Landslide on Road E87 Burgas – Malko Tarnovo, Bulgaria

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Abstract

Bulgaria is a country with a relief of various elevations. This is a precondition for appearance of landslides of different types. The present study deals with stabilizing approaches for a landslide on the road between two towns in Bulgaria.

The landslide covers 63 m of the main road connecting the Bulgarian Black Sea capital of Burgas and the border between Bulgaria and Turkey. This road, I-9, is a first-class road which coincides with European Road E87 and passes through Bulgarian territory from north to south.

In the spring of the year 2010 two parallel cracks appeared in the road near the km 282+000 mark and the road sank 2,5 m. The terrain of the landslide is steep with an inclination of 36º - 42º. The geological survey shows back filling, slope washed gravels and weathered bedrock to a depth of 12 m. Bed rock of marls is found below this depth. The sliding surface is a polygonal line. Stability calculations are made and an uncompensated landslide load is determined.

Different approaches are used for stabilizing of the landslide – piles, anchors, drainage ribs and retaining walls, geo grids as well as their combinations. The typical anchors construction was not possible to be used because of the steep terrain and joint work of two rows of piles was designed instead. The road has been restored and under exploitation.

Keywords: landslide, slope stability, piles, anchors, retaining wall, drainage ribs

1 Introduction

Bulgaria is a country with a relief of various elevations. This is a precondition for the occurrence of landslides of different types (Bruchev, 1994).

The landslide discussed in this paper covers a 63,00 m section of the layout of Road I-9 Burgas – Malko Tarnovo at km 282+000. The road connects the Bulgarian Black Sea capital Burgas and the Bulgarian-Turkish border. It is a first class road which coincides with European Road E87 and passes through the Bulgarian territory from north to south.

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The section considered is located in Southeast Bulgaria, in the Strandzha Mountains. The ground on which the landslide occurred is a 36º-42º gradient slope facing west-southwest.

The road has a mixed-type structure, partly in excavation and partly in embankment. A drain ditch is made over the road.

2 History of the Site

In the period 1998-1999 the ditch got silted-up. The surface water from the spring rain and snow melt infiltrated the embankment thus creating a hydrodynamic pressure and decreasing the shear strength properties of the marl bedrock. A landslide was triggered.

A retaining structure was built up in 1999. It is a pile system of one pile row combined with a foundation grill upon which an angular retaining wall and backfill of aggregates is laid. The road drainage ditch was reconstructed and a culvert under the road was made.

A landslide was triggered again after the 2010 spring snow melt causing a total vertical collapse of the right lane to approx. 2,50 m and horizontal displacement of part of the central lamellas of the retaining wall with amplitude of 10,00-20,00cm. Some lamellas, together with the piles underneath, were completely destroyed. Numerous descending springs were observed in the last one third of the landslide body and the toe was established in the floodplain of the river flowing in the slope base. The landslide has the following dimensions: landslide body area – 2210,0 m^2, length – 80,0 m and depth – up to 11,0 m.

Figure 1 and Figure 2 show the road pavement failures due to the 2010 landslide.

Figure 1: A photo of the road section affected by the 2010 landslide in the direction of the town of Malko Tarnovo

Figure 2: A photo of the road section affected by the 2010 landslide in the direction of the city of Burgas

3 Engineering Geological Conditions

Different types of rocks and soils are found in Strandzha Mountains – granite, gabbro, marble, limestone and marl as well as weathered and eroded materials (Angelov etal, 1992).

Geological investigations were carried out in the section affected in October 2010 which included boreholes, geophysical profiles with ground penetrating radar and laboratory geotechnical tests of soil samples from the established lithological varieties. The location of the landslide and the exploratory boreholes is presented in Figure 3.

The exploratory boreholes and geophysical profiles reveal four engineering-geological varieties. Their location is presented on engineering-geological cross-section I – I, Figure 4.

Aggregates from the road bed and asphalt pavement was established from ground level to a depth of 4,10 m. The layer is composed and compacted as a backfill of the compromised retaining wall and reached the vertical alignment of the roadway.

Slope washed gravels with clayey-sandy filler are found under the aggregates up to a depth of 10,9 m. Ground water has been established in those sediments.

Grayish-blue to grayish-black marls, highly fractured, have been determined under the slope washed gravels. During the drilling operations those sediments are additionally crushed, their total thickness is not passed to a depth of 25 m.

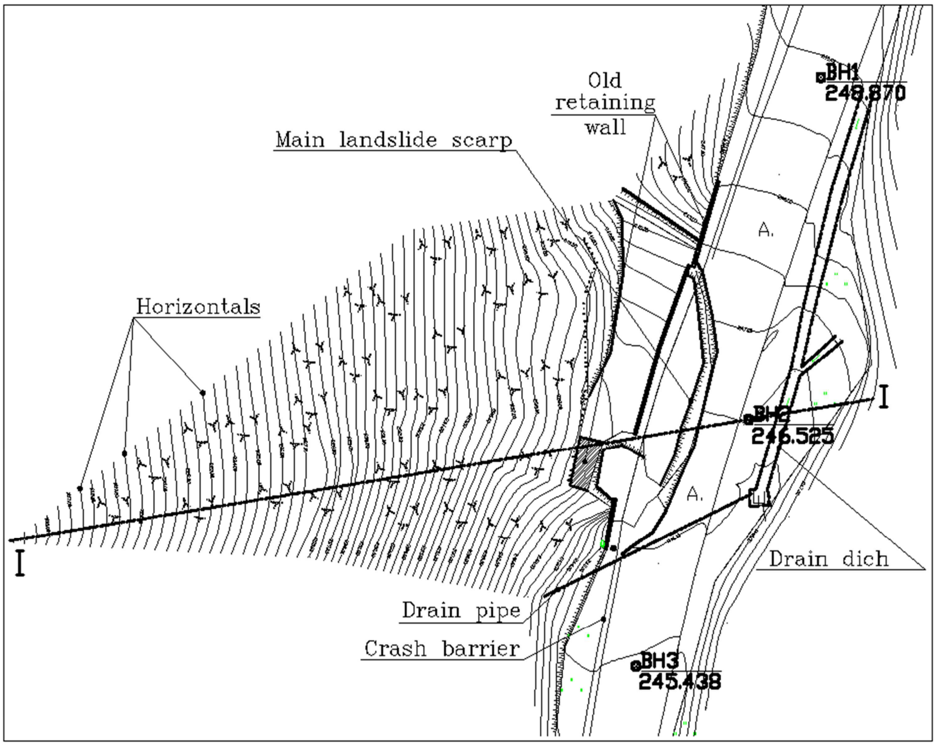

Figure 3: Scheme of the situation of the landslide section on the Burgas - M. Tarnovo road in 2010

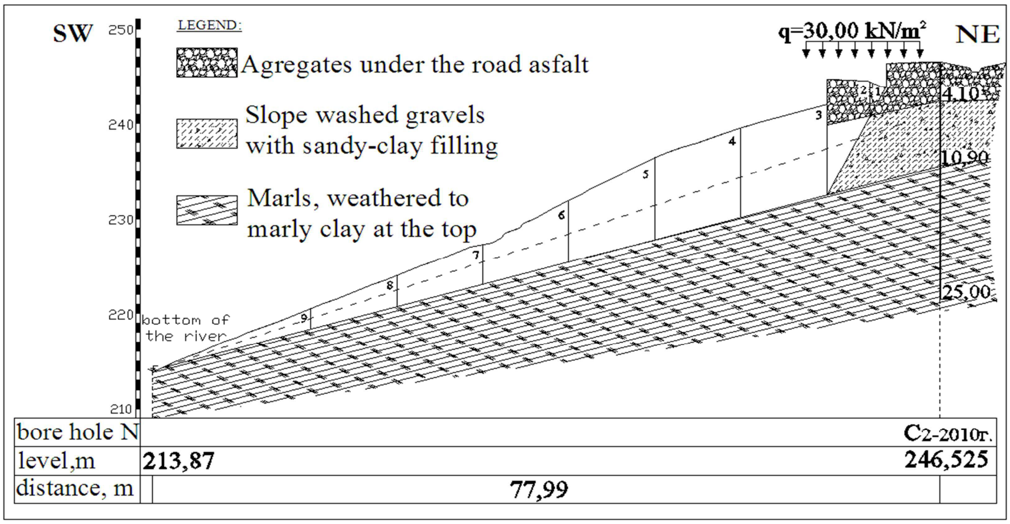

Figure 4: Engineering-geological cross-section through the landslide along line I – I

The uppermost part of the marls is highly weathered and chemically altered to marl clays. These clays have a small thickness (approx. 0,2 to 0,5 m). A sliding surface has been determined in them. The geotechnical lab tests show the following indices for the physical and mechanical properties of that variety:

Specific gravity ρ_s = 2,71 g/cm^3
Bulk density ρ_n = 2,03 g/cm^3
Dry density ρ_d = 1,71 g/cm^3
Void Ratio e = 0,588
Water content W_n = 19,10 %
Liquid limit L_l = 24,0 %
Plastic limit L_p = 15,0 %
Plasticity index I_p = 9,0 %
Consistency index I_c = 0,54
Degree of saturation S_r = 0,88
Ultimate angle of internal friction φ =25,55°
Ultimate cohesion c = 0,18 kPa
Residual friction angle φ = 22,80°
Residual cohesion c = 0,09 kPa

These sediments are determined as sandy clay in medium hard consistency.

The engineering-geological inspection of the road embankment and the compromised load-bearing retaining structure and the data on the field geological survey activities show that the main reasons for triggering the landslide processes in 2010 were the malfunction of the drainage system and the insufficiently secured retaining structure.

4 Landslide Stability Calculations

The great variety of landslide phenomena by genesis, type of sliding surface, size and mechanism of occurrence and development presuppose a differential approach to determining the stability of slopes and scarps.

Depending on the particular engineering-geological conditions and manner of manifestation of the landslide in question, the Janbu method (Janbu, 1957) was chosen to determine the stability coefficient. This method is widely used for landslide surfaces realized along a polygonal slip surface.

The slope stability assessment is made on the engineering-geological profile I-I (Figure 4).

The layers' characteristics used, as unit weight, angle of internal friction and cohesion are determined by DA2 (BDS-EN 1997, 2004) and given in Table 1**Error! Reference source not found.**. Values for unit weight of submerged soil and saturated soil are not given for layer 1 since no groundwater was established in it. Due to the small thickness of layer 3, the water in it does not form hydrostatic or hydrodynamic pressure.

Index	layer 1	layer 2	layer 3
Unit weight, γ, kN/m^3	22,00	20,00	22,50
Unit weight of submerged soil, γ', kN/m^3	-	11,10	-
Unit weight of saturated soil, γ_r, kN/m^3	-	21,10	-
Angle of internal friction, φ, °	33,00	20,08	19,00
Cohesion, c, kPa	5,00	16,50	5,00

Table 1: Soil characteristics used for the calculations

The slope stability assessment was made for different conditions and combinations of conditions. The effect of the water level, seismic force and dynamic loading of the roadway (30,00 kPa distributed load) was taken into account. The stability safety coefficients are presented in Table 2.

Type of load	Stability safety coefficient
Slope under natural condition	1,172
Slope under raised groundwater level	1,012
Slope under raised groundwater level and seismic force	0,857
Slope under raised groundwater level and roadway dynamic loading	0,982
Slope under raised groundwater level, dynamic loading and seismic force	0,837

Table 2: Calculated stability safety coefficients

From the calculations performed it is possible to make the following conclusions:

- Under natural condition, without roadway dynamic loading, the slope is in stable condition – the favorable forces are bigger than the unfavorable.

- Under the influence of a raised groundwater level, especially under additional dynamic road loading, the slope transfers to unstable condition – the unfavorable forces are bigger than the favorable.

- If the seismic force is taken into account, then it becomes impossible to meet the minimum stability safety coefficient of 1,15 (Regulation №01/12,2002).

5 Strengthening Approaches

Combined structural and drainage approaches have been designed and carried out based on the analysis of the reasons, engineering-geological investigations, geotechnical investigations and stability calculations concerning the landslide strengthening.

Lowering the ground level in the landslide area to a depth of 2,0-2,5 m was designed as a first step with the purpose of creating better possibilities for positioning building machines and equipment.

Structures of two rows of borehole piles were built in the landslide area, each being 500 mm in diameter and driven to a depth of 15 m (Figure 5**Error! Reference source not found.**).

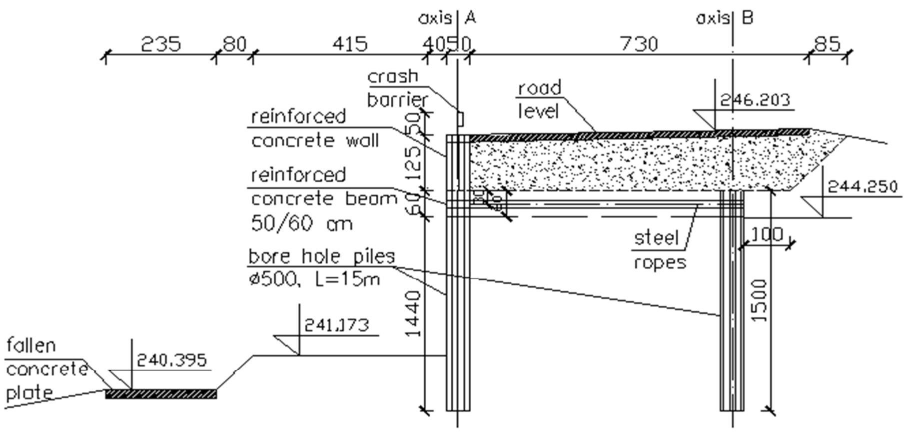

Figure 5: Design of structural approaches

The first row on the side of the collapsed section takes up the landslide pressure. The landslide forces on the first pile row are determined to be 137,3 kN/m. The piles of that row are calculated as a supported structure in which part of the force (84,7 kN/m) is taken up by the marl bed rock under the sliding surface. The other part of the force (52,6 kN/m) is transferred to the anchors.

The anchors are made of insulated steel ropes and anchored in a second row of piles located on the other side of the road. The second row of piles is designed to additionally stabilize the slope over the road. The advantage of the ropes over rigid connection is in the possibility to install them easily. They are flexible in case of possible subsidence of the roadway above, are laid deep under the roadway and are much cheaper.

The first row piles stressed state under the level of the sliding surface has been determined: maximum value of the bending moments – 118,2 kNm/m and displacement at the pile head – 1,0 cm.

A retaining wall is being built over the piles on the landslide side which is practically continuation of the piles.

The usual crash barrier is placed over the wall.

After the wall is laid, backfill is made and asphalt is placed to the road level.

For providing better connection between the embankments over the collapsed section and non-collapsed part, high strength geo grid is laid at every two layers of embankment.

Drainage measures are envisaged along with the structural ones. The ditch over the road is cleaned and the water is carried away through a 1000 mm diameter drain pipe passing under the road and is discharged in the gully.

Three drainage ribs, filled with gravels, are designed for additional drainage of the embankments (Figure 6).

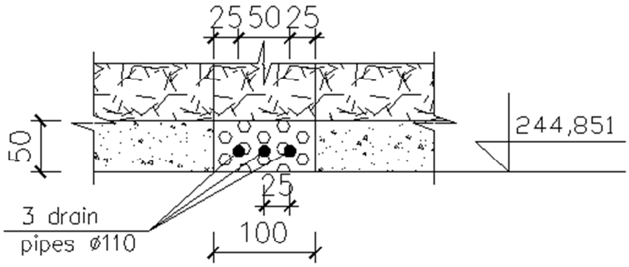

Figure 6: Scheme of a drainage rib

The drainage ribs are built together with the embankments. Drain pipes are laid in the bases of the excavations for the drainage ribs.

6 Discussion

Various combinations of structural and drainage approaches were tested in determining the methods for stabilizing the landslide on the road Burgas - Malko Tarnovo at km 282+000. The inefficiency of the retaining structure built and compromised in 1999 was taken into account. It was found that a retaining structure of one row of piles, if the slip surface is at a depth of 12 m, requires piles with large diameters and high driving depth. In this case the landslide pressure causes considerable displacements in the roadway.

The construction of a second row of piles which can take up the anchor forces of the first row of piles proved to be a secure and appropriate structure in static and technological respect.

The importance of that road demanded fast and effective execution of retaining and drainage structures thus ensuring stabilization of the terrain and the commissioning of the road.

The geodetic measurements do not indicate deformations since the road was restored. The road has been in operation since 2010.

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